ACCELERATION OF A PLASMA BY ITS OWN RADIATION

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If the radiation of a plasma is anisotropic, so that its intensity along $\vec{q}$ is lower than in the opposite direction by an amount I_q [erg/sec], then the photon yield from the plasmoid is accompanied by a rocket thrust with force $f_q = I_q\vec{q}/cq$. Under suitable conditions, such a photon thrust can serve as an effective plasmoid accelerator.

Let us stop briefly to discuss the example of a highly-ionized plasma with inverted population at two states of the atoms (or ions), with a difference ε between the energy levels. This plasma can amplify a radiation of frequency $\varepsilon/h = \nu$. If the amplification is large, when light with wave vector $\vec{k}$ (in the frame of the plasmoid, $k = 2\pi\nu/c$) is incident on the plasma from the outside, the thrust of the amplified radiation in the direction opposite to $\vec{k}$ will exceed by many times the pressure applied to the plasmoid by the incident light.

Calculations [1] have shown that if the free electrons of a highly-ionized plasma are deeply cooled, then a sufficiently strong population inversion is reached after a time shorter than the relaxation time of the corresponding states. The most favorable for an intense emission is a cyclic regime of alternating heating and cooling cycles [2]. Means of deeply and rapidly cooling free electrons are discussed in a number of papers. It is easy to see that cooling methods [2] based on collisions between electrons and cold heavy plasma particles and ambipolar diffusion to the walls contradict the requirments of effective acceleration. On the other hand, the cooling method [3] connected with an abrupt decrease of the magnetic field surrounding the plasma with the main conditions of this problem.

Let a magnetized highly-ionized plasmoid of density $10^{14} - 10^{18}$ cm^{-3} move along the force lines of a magnetic field. The centroid of the plasmoid remains on the average on the same "central" circular orbit, which coincides with the force line at which the field is minimal. The magnetic field increases sufficiently steeply on all sides of the central orbit, preventing the magnetized plasma from diffusing transversely to the orbit. The external radiation is applied to the plasma on sections of its inverted population; its wave vector

($k_n = [(1 - v/c)(1 + v/c)]^{1/2}\vec{k}$ in the lab) is directed opposite to the plasmoid velocity $\vec{v}$. Heating is by a pulsed magnetic field that compresses the plasma strongly. Cooling upon removal of this additional field is connected with adiabatic expansion of the plasmoid and with emission of radiation. The intensity (and pressure) of the directed radiation along the inversely-populated medium increases in the direction of $\vec{k}$. This leads to convective mixing in the plasmoid and to the appearance of a force hindering the diffusion of the plasmoid along the magnetic force lines. The rapid modulation of the field intensity, used for heating and cooling, prevents occurrence of toroidal drift [4]. The plasma radiation serves here as a low-inertia source of detailed information that makes it possible to correct, with the aid of an external field, the deviations of the plasmoid from the central orbit as a result of fluctuation departures from its cyclic mode.

Recognizing that the maximal thrust is independent of v in the plasmoid reference frame we obtain, assuming that the frequency is properly adjusted, as an estimate of the plasmoid acceleration in the lab (see also [5]) $a \approx a^{(0)}(1 - v/c)$, $a^{(0)} = \varepsilon\delta/cMT$, where δ – fraction of all the plasma atoms (ions) participating during the cycle in the radiation amplification, M – rest mass of the atom (ion), T – duration of the heating and cooling cycle in the lab system. To estimate $a^{(0)}$ we shall use very simple examples of an analysis of the relaxation of the plasma population following abrupt cooling of the free electrons. For atomic hydrogen, putting $\varepsilon_H \approx 0.66$ eV, $\delta_H = 0.1$, and $T_H = 10^{-8}$ sec, we get $a_H^{(0)} \approx 2 \times 10^8$ cm/sec^2. For a plasma of hydrogenlike ions of an element with atomic Z (in the periodic system) we can put in principle [2] $\varepsilon_Z = Z^2\varepsilon_H\delta_{(Z)} = \delta_H$, $M_{(Z)} \approx 2M_H Z$, $T_Z \approx Z^{-4}T_H$, and then $a_{(Z)}^{(0)} \approx Z^5 a_H^{(0)}$. It should be noted that the role of the nonradiative transitions in a plasma of multiply charged ions diminishes, making it possible to obtain amplification at relatively large densities, and that with increasing Z the contribution of the electrons of recombination radiation and bremsstrahlung to the cooling increases.

The conditions for the production of an amplifying Li plasma are in many respects simpler than for a hydrogen plasma. For a dense lithium plasma [1] we put $\varepsilon_{Li} = 1.8$ eV, $\delta_{Li} = 0.1$, $M_{Li} = 6M_H$, and $T_{Li} = 10^{-8}$ sec; then $a_{Li}^{(0)} \approx 6 \times 10^7$ cm/sec^2. The required temperature range in the heating-cooling cycle is smaller by a factor of 8. The population inversion in a dense Li plasma, unlike in H (or H-like ions), is produced by nonradiative transitions, so that the reabsorption of the radiation is practically negligible. Plasmoids with large dimensions and densities are optimal; they have a larger ratio of directed to isotropic radiation. The possibility of appreciable reflection of the amplified radiation from the forward more-ionized part of the dense plasmoid should be investigated, for this might make it possible to dispense with an external radiation source.

Acceleration by the intrinsic radiation can apparently also be used to produce fast continuous molecular jets, using the inverted population in weakly-ionized gases.

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